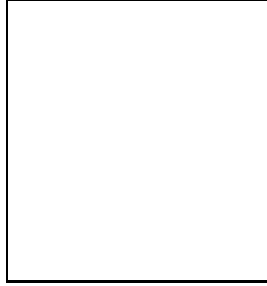


RECENT RESULTS FROM CLEO

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Between 1990 and 2001, the CLEO II/II.V/III detectors at the Cornell Electron Storage Ring (CESR) have recorded over of 34 million B decays and nearly 60 million charm decays. A selection of the latest results in the electroweak sector from these data sets has been presented. The focus is placed on the determination of the CKM matrix elements $|V_{ub}|$, and $|V_{cb}|$, and how the measurement of the $b \rightarrow s\gamma$ photon spectrum can be used to reduce theoretical uncertainties.

1 Introduction

1.1 The CLEO experiment

The data presented here have been recorded with the CLEO detector at the symmetric 10.58 GeV e^+e^- collider CESR at Cornell University, NY, USA. The center of mass energy is chosen to produce $\Upsilon(4S)$ mesons in resonance, which decay predominantly into a pair of B mesons. The rest of the collisions produce non-resonant $q\bar{q}$ pairs. One third of the data were recorded at a center of mass energy of approximately 60 MeV below the resonance (*off-resonance*), to be used for background studies.

During the CLEO II and II.V phases of the experimental program almost 10 Million $B\bar{B}$ pairs have been recorded in the years 1990–2000. This corresponds to an on-resonance luminosity of $\approx 9 fb^{-1}$ and is the subject of this proceedings. Between 2000 and 2001, an additional $7 fb^{-1}$ (on-resonance) have been recorded with an upgraded detector, CLEO III. Analysis on this data is in progress, and the results are expected to considerably reduce experimental errors from many previous measurements.

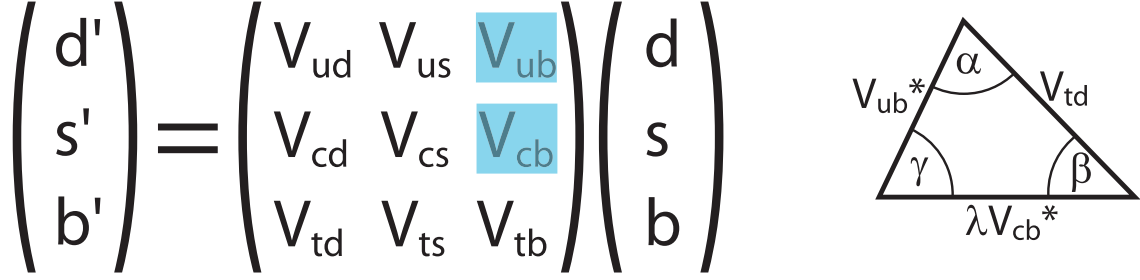


Figure 1: Left: CKM matrix. The elements that are highlighted are subject of this presentation. Right: Unitarity triangle. Only the parameters relevant for this presentation are indicated. λ is the experimentally well measured sine of the Cabibbo angle.

1.2 The CKM matrix

The Cabibbo-Kobayashi-Maskawa matrix¹ describes the weak couplings between the quarks in the Standard Model through 9 fundamental parameters, see Fig. 1 left. Measurements of those parameters allow one to test existing theories and can give constraints on physics phenomena beyond the Standard Model. This Model requires that the matrix be unitary, which is commonly displayed through the “Unitarity Triangle”,² see Fig. 1 right. The knowledge of all three angles of the triangle is also likely to establish a clear understanding of CP violation in the b quark sector.

The CKM matrix element $|V_{cb}|$ sets the length of the base of this triangle. It has been previously measured with an accuracy of $\approx 5\%$.³ The element $|V_{ub}|$ bears the largest uncertainty for measurement of a second side, $\approx 30\%$.³ We will show that these errors have been considerably reduced using new analysis techniques and larger data samples.

2 How to measure $|V_{cb}|$ and $|V_{ub}|$

The measurements of $|V_{cb}|$ and $|V_{ub}|$ are carried out using the semileptonic quark decays $b \rightarrow c\ell\nu$ and $b \rightarrow u\ell\nu$, where ℓ is any lepton – typically e or μ . These decays provide a clear experimental signature (a single high energy lepton), and are well accessible to theoretical calculations. Heavy Quark Effective Theory⁴ (HQET) has proven to be a phenomenological approach that is able to provide quantitative predictions for observables with uncertainties that lie within the experimental errors. The method initially calculates an observable assuming the heavy quark in the decay to be infinitely heavy. It then determines corrections in powers of $1/m_B$, where m_B is the B meson mass. Two approaches are pursued:

2.1 Exclusive measurements

A suitable decay channel is chosen for exclusive measurements, relying on the ability to fully reconstruct one of the B mesons into known final states. To derive the CKM matrix element, knowledge of the hadronic form factor that is specific for the decay is needed. The form factors have not been measured with sufficient accuracy, and they can usually not be calculated over the full kinematic range. For $|V_{cb}|$, HQET can access them in the range of maximum momentum transfer between the heavy quark and the $\ell\nu$ system. Using the relation $d\Gamma_{\text{exclusive}}/dw = \text{const} \times F(w)|V_{cb}|$, where $F(w)$ is the form factor as function of the kinematic variable w , we

can determine $|V_{cb}|$ by extrapolating the measured decay width $\Gamma_{\text{exclusive}}$ to $w = 1$. This corresponds to the case of maximum momentum transfer. HQET works well in exclusive $b \rightarrow c$ decays, because $1/M_B$ is small and $1/M_{D^{(*)}}$ is also small. For $|V_{ub}|$, one needs another way to compute the form factor, e.g. Lattice QCD.

2.2 Inclusive measurements

An inclusive analysis determines the branching fraction $\mathcal{B}(B \rightarrow X_q \ell \nu)$, where X_q is any hadron produced in the quark decay $b \rightarrow q \ell \nu$ ($q = c, u$). The experimental identification of this hadron is subject of detailed investigation and a source of considerable systematic uncertainties. Using the measured branching fraction, one can determine the CKM matrix element $|V_{qb}|$ from expressions provided by HQET. This requires to make the assumption of *quark-hadron duality*, which means that it is justified to use calculations made on the quark level to describe hadronic processes, if we integrate over a sufficiently large number of hadronic final states and sufficiently large fraction of phase space. In considering the analysis results, it is as well possible to judge the extent to which this is true. As we will point out below, we have used experimentally measured parameters from another CLEO analysis, the measurement of the $b \rightarrow s \gamma$ photon spectrum, to minimize the theoretical uncertainties.

3 CLEO measurement results

3.1 $B \rightarrow D^* \ell \nu$

The branching fraction of $B \rightarrow D^* \ell \nu$ is the highest among the exclusive branching fractions of the B meson, $\approx 5\%$.³ In the corresponding recent CLEO analysis,⁵ 3.3 Million $B\bar{B}$ from the CLEO II experiment have been used. The event reconstruction identifies the desired signatures by searching for the decay of charged and neutral D^* mesons to a $D\pi$ pair. The background spectra are obtained from off-resonance data and, to a small part, Monte Carlo simulation. The relative contributions of $B \rightarrow D^* \ell \nu$ and $B \rightarrow D^* X \ell \nu$ are fitted to the data.

The differential decay width $d\Gamma_{\text{exclusive}}/dw$ for the decay $B \rightarrow D^* \ell \nu$ can be expressed as a function of $|V_{cb}|F(w)$, where w is a kinematic variable that is equal to the scalar product of the 4-vectors of the B meson and the D^* . It ranges from $w = 1$ (max. momentum transfer, *zero recoil*) to $w \approx 1.5$. The extrapolation of $|V_{cb}|F(w)$ to $w = 1$ yields $|V_{cb}|F(1) = 0.0431 \times (1 \pm 3\% \pm 4.2\%)$, where the first error is statistical, and the second systematic. Using $F(1) = 0.919^{+0.03}_{-0.035}$ from a recent lattice QCD calculation,⁶ we determine $|V_{cb}| = 0.047 \times (1 \pm 3\% \pm 4.2\% \pm 3.8\%)$, where the third error comes from $F(1)$. This result is the single most precise $|V_{cb}|$ exclusive measurement to date.

3.2 $B \rightarrow \rho, \pi \ell \nu$

The exclusive analysis to determine $|V_{ub}|$ investigates the decay channels $B \rightarrow \rho, \pi, \omega \ell \nu$. By the time of the Moriond 2002 conference it has been ongoing both utilizing the full CLEO II and CLEO III datasets, relying on a refined procedure for neutrino reconstruction.⁷ The background is determined in a similar way as for the $B \rightarrow D^* \ell \nu$ work. Since the form factors for the considered channels are not as well known, the analysis will actually be able to provide constraints on the existing form factor models. A $|V_{ub}|$ measurement with a total uncertainty of $\approx 15\%$ is expected to be available by summer 2002. It will supercede previous CLEO measurements,^{8,9} which are accurate to $\approx 20\%$.

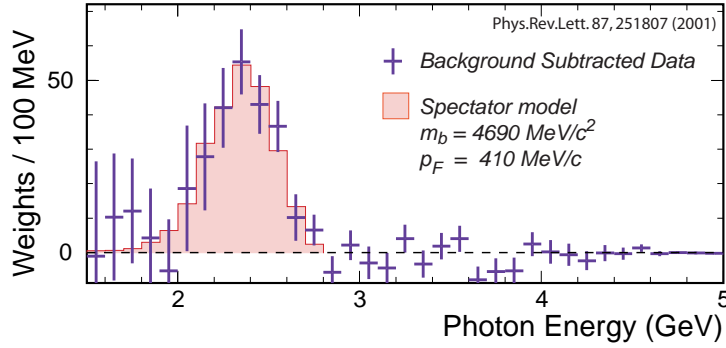


Figure 2: Photon spectrum for $b \rightarrow s\gamma$. The background subtracted data (data points) have been fitted to an HQET expression (Spectator model) with the mean energy as free parameter.

3.3 $B \rightarrow s\gamma$

The recent CLEO analysis¹¹ measuring the properties of the inclusive decay $B \rightarrow X_s\gamma$ has been able to supply a valuable input for all other inclusive semileptonic channels: the $b \rightarrow s\gamma$ photon spectrum. The previous CLEO measurement¹² of the inclusive $b \rightarrow s\gamma$ branching fraction was of significant interest to the theoretical physicist, but the resulting photon spectrum was not sufficiently precise for comparison with HQET predictions. After using the full CLEO II and II.V dataset and improving the $B\bar{B}$ background suppression considerably, the resulting spectrum (see fig. 2) allows the determination of the HQET parameter $\bar{\Lambda}$.

This parameter is a measure for the light degrees of freedom in the B meson. The mean photon energy can be expressed as follows: $\langle E_\gamma \rangle = 1/2 M_B f(\bar{\Lambda}/M_B)$, where M_B is the B meson mass, and $f(\bar{\Lambda}/M_B)$ is a known function that is (approximately) independent of the B decay channel. We find $\bar{\Lambda} = 0.35 \pm 0.08 \pm 0.1$ GeV.

3.4 $B \rightarrow X_c \ell \nu$

The mean of the charmed hadron mass spectrum in the inclusive channel $B \rightarrow X_c \ell \nu$ has been predicted by HQET:¹³ $\langle M_X^2 - M_D^2 \rangle = f(\bar{\Lambda}, \lambda_1)$, where f is a given function of the above determined parameter $\bar{\Lambda}$, and a second HQET parameter, λ_1 , which is a measure for the average momentum of the b quark in the B meson. The expression gives the mean hadronic mass with respect to the D meson mass M_D and has been obtained to order $1/M_B^3$, in the \overline{MS} renormalization scheme. It is thus possible to derive λ_1 from the hadron spectrum measurement. In the corresponding CLEO analysis,¹⁴ a powerful background suppression is employed by only using lepton momenta above 1.5 GeV and applying the CLEO neutrino reconstruction method.

Combining this measurement with the $\bar{\Lambda}$ (see fig. 3) result from the $b \rightarrow s\gamma$ analysis allows the determination of $\bar{\Lambda} = 0.35 \pm 0.07 \pm 0.1$ GeV, and $\lambda_1 = -0.236 \pm 0.071 \pm 0.078$ GeV.

The determination of $|V_{cb}|$ is now possible using an expression¹⁵ that links the full semileptonic decay width Γ_{sl} to $|V_{cb}|$ times a function $h(\bar{\Lambda}, \lambda_1)$. $\Gamma_{sl} = (0.427 \pm 0.02) \times 10^{-10}$ can be obtained from previous CLEO measurements of $\mathcal{B}(B \rightarrow X_c \ell \nu)$,¹⁶ the B meson lifetime τ_{B^\pm} ,³ and the ratio of charged to neutral B meson production rates f_{+-}/f_{00} .¹⁷ The final result is $|V_{cb}| = 0.0404 \times (1 \pm 2.3\% \pm 1.3\% \pm 2\%)$. The total error of 3.2% is the lowest for any measurement. It needs to be mentioned again that the assumption of quark-hadron duality is made for this conclusion.

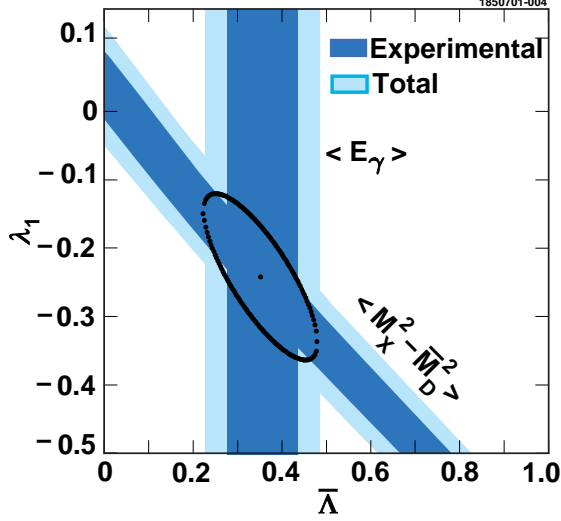


Figure 3: Determination of the HQET parameters $\bar{\Lambda}$ and λ_1 by combining the measurement results for the $b \rightarrow s\gamma$ photon spectrum ($\langle E_\gamma \rangle$) and the $B \rightarrow X_c \ell \nu$ hadronic mass spectrum ($\langle M_X^2 - M_D^2 \rangle$).

3.5 $B \rightarrow X_u \ell \nu$

Measuring $|V_{ub}|$ has been historically difficult, because of theoretical uncertainties. One experimental reason is the fact that semileptonic B decays are highly dominated by $b \rightarrow c$ transitions, which are favored over $b \rightarrow u$ by two orders of magnitude. A technique that has been applied in earlier works¹⁸ exploits the kinematic situation of the decay by measuring the lepton momentum spectrum in the kinematic end region towards higher lepton momenta, where the $b \rightarrow c$ decays are suppressed due to momentum conservation. For the current analysis¹⁹ this method has been refined through the improvement of the $B \rightarrow X_c \ell \nu$ Monte Carlo modeling, which could be achieved using recent form factor measurements and a more precise HQET description. Also, the continuum suppression was strongly improved through the use of a neural net, which lead to a reduction in model dependence.

The full decay width for $B \rightarrow X_u \ell \nu$ is required for the $|V_{ub}|$ determination. Since we only measure the spectrum in the end point region, we determine the measured fraction of the distribution f_u by fitting the measured $X_u \ell \nu$ lepton energy spectrum to a nonperturbative shape function.¹⁰ This shape function can be obtained from the photon energy spectrum in the $b \rightarrow s\gamma$ analysis.¹¹ We find the full decay width by dividing the measured partial width by f_u , then extract $|V_{ub}|$ using the following equation:²⁰

$$|V_{ub}| = (3.07 \pm 0.12) \times 10^{-3} \times \left(\frac{\mathcal{B}(B \rightarrow X_u \ell \nu) \times 1.6 \text{ ps}}{0.001 \tau_B} \right)^{\frac{1}{2}}. \quad (1)$$

The choice of the optimal momentum interval for $|V_{ub}|$ is a compromise between the limited knowledge of the $B \rightarrow X_c \ell \nu$ background and the uncertainty in f_u . The results for various intervals are consistent with each other. We choose the lepton momentum interval between 2.2 and 2.6 GeV: $|V_{ub}| = 0.00408 \times (1 \pm 8.3\% \pm 10.8\% \pm 3.9\% \pm 5.9\%)$. Assuming that quark-hadron duality holds for this analysis, we consider this result to be the best $|V_{ub}|$ determination to date.

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